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Geology of the Westernport Sunkland

By D. Spencer-Jones,* M. A. H. Marsden,† C. M. Barton,‡
J. J. Carrillo-Rivera*

Abstract: The Westernport Sunkland is a broad, low-lying physiographic unit resulting from the interplay of block faulting, vulcanicity and non-marine and marine sedimentation during the Cainozoic Era. In the early Tertiary widespread basic vulcanicity with minor sedimentation was followed by a period of erosion. In early to middle Miocene subsidence of the area resulted in an extensive marine transgression with the deposition of marls and limestones. As the sea retreated in late Miocene to Pliocene, fluviatile sediments infilled channels and covered most of the area. Data from drilling and surface mapping have enabled the presentation of revised distributions and interpretations of the Tertiary units within the Sunkland.

The Quaternary tectonics and sealevel changes in the Sunkland are complex, and resulted in the development of the onshore land forms, and also the development of intertidal and subtidal morphological systems. Eight of these are recognized. The complex distribution and movement patterns of sediment types in the channels, on banks and tidal flats, result primarily from tidal currents.

Geotechnical drilling along the main shipping channels has revealed new information on the engineering properties of the sediments and sub-strate. High areas in the outer part of the Bay are composed mainly of Quaternary clayey conglomerate and uniform sands. In contrast, the inner channel is generally floored by soft ($< 0 \cdot 35$ Mpa, UCS) Quaternary silty clays. Deep weathering montmorillonitic clay profiles, in Tertiary basalt at Stony Point, show a progressive downward increase in clay stiffness. Engineering properties of other snb-channel materials are briefly considered.

The important Tertiary aquifer systems beneath the Koo-wee-rup/Dalmore areas in the northern part of the Sunkland are a valuable irrigation water resource, and control measures will be necessary to prevent overdevelopment and saline water intrusion.

INTRODUCTION

The aim of this paper is to present a summary of the geology of the Westernport Sunkland and in particular to outline some of the geological work, either recently completed or underway, in the fields of stratigraphy and structure (Victorian Mines Department; Geology Department, University of Melbourne), in recent sedimentation (Geology Department), and in the applied fields of hydrogeology (Mines Department), and geotechnology (Division of Applied Geomechanics, CSIRO).

The Westernport Bay area has been studied in detail by geologists for many years and reference to the publications produced will give detail on specific areas. Keble (1950) published a report on the geology and economic resources of the Mornington Peninsula and Jenkin (1962, 1974) and Thompson (1974) have described the physiography, geology and hydrogeology of the Westernport Bay area. Hydrogeological maps have been prepared by Carrillo-Rivera (1974).

In recent years studies have been undertaken within Westernport Bay by the State Electricity Commission (Learmonth & Garrett, 1966); Geology Department, University of Melbourne (Marsden & Mallett 1974); Ports and Harbors Division of the Public Works Department (Barton 1974) and the Victorian Mines Department in collaboration with the Commonwealth Bureau of Mineral Resources (Gunn 1973). Geological contributions to the Westernport Bay Environmental Study are being made by the Mines Department (geology, geophysics and hydrogeology), the

* Victorian Department of Mines, Russell Street, Melbourne, Victoria 3000.
† Department of Geology, University of Melbourne, Parkville, Victoria 3052.
‡ CSIRO Division of Applied Geomechanics, P.O. Box 54, Mount Waverley, Victoria 3149.

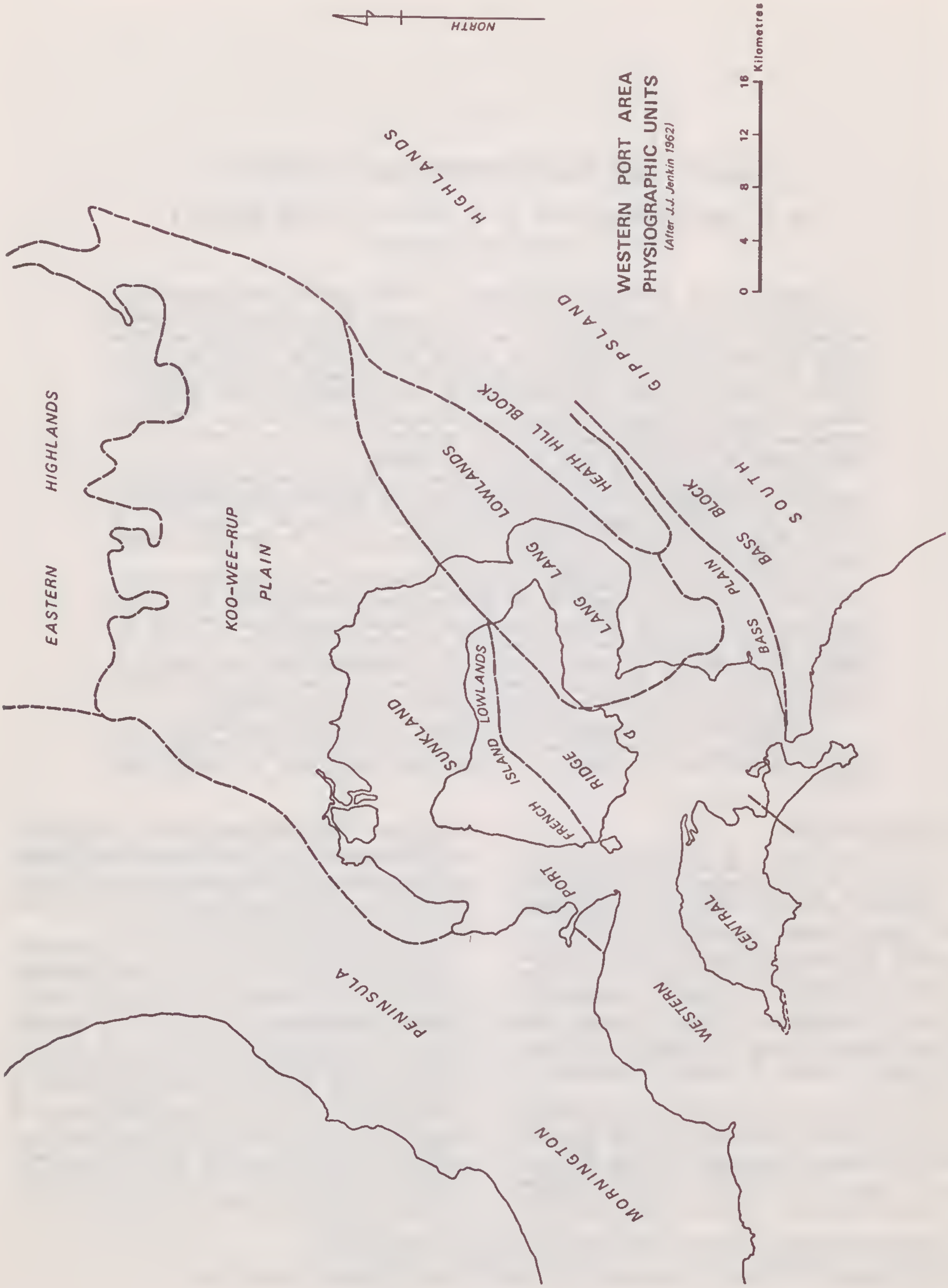

FIG. 1—Westernport area physiographic units.

Geology Department, University of Melbourne (geophysics, morphology and sedimentation).

The Westernport Sunkland as a physiographic feature is a product of block faulting and the resulting interplay of early Tertiary vulcanicity followed by nonmarine and marine sedimentation during the Cainozoic Era. Hence it is comparable to the Port Phillip Sunkland.

Normal faults with pronounced topographic scarps define the eastern and western limits of the Sunkland and, as will be explained later, other faults determine physiographic units within it.

The most extensive marine transgression in the Tertiary occurred during Early to Middle Miocene when widespread marl and limestone were deposited. As the sea retreated during late Miocene to Pliocene, the area was covered by fluviatile sediments leaving the flat-lying topography between Longwarry and Koo-wee-rup. The fluviatile deposits were subsequently covered by Quaternary aeolian sand sheets and dunes, resulting in a poorly developed drainage system and swamps.

Prior to settlement the extensive plain at the head of the Bay was covered by thick scrub, and the central area of this plain was referred to as the 'Koo-wee-rup Swamp' because of its waterlogged condition during most of the year. Artificial drainage systems were developed as early as 1876, and an extensive drainage scheme completed in 1920 by the State Rivers and Water Supply Commission. This drainage included an irrigation system using water from the Bunyip River.

PHYSIOGRAPHIC UNITS

Aspects of the physiography of the area have been referred to by Hills (1942) and later described in detail by Jenkin (1962) and Marsden and Mallett (1975). The following are the most important units (Fig. 1):

1. The Mornington Peninsula

The Mornington Peninsula Horst is bounded by the Selwyn Fault to the west and the Tyabb Fault and Clyde Monocline to the east. The Peninsula consists of Palaeozoic sedimentary and granitic rocks covered to the south and southeast by a thick sequence of early Tertiary volcanics. It separates Port Phillip Sunkland from the Westernport Sunkland with the main ridge reaching 300 m above sea level.

2. South Gippsland Highlands

These Highlands, which form the eastern limit of the Sunkland, consist of tilted blocks between the Bass, Heath Hill and other normal faults. They comprise Mesozoic (Lower Cretaceous) sedimentary rocks with some Tertiary sediment cover. Both the Bass and Heath Hill Faults are represented today by pronounced topographic escarpments.

3. Eastern Highlands

The undulating country forming the northern edge of the Sunkland represents the foothills of the Eastern Highlands. The hills are composed of Silurian-Devonian sedimentary rocks and Devonian granitic rocks. Residuals of early Tertiary volcanics and sediments cap some of the foothills and Jenkin (1962) suggests that the northern edge of the Sunkland is not due to faulting but results from a gentle southerly downwarp. The old topography eroded in the Palaeozoic rocks passes down beneath the Cainozoic volcanics and sediments of the Sunkland.

4. The Westernport Sunkland

This is the area which lies between the Mornington Peninsula Horst and the South Gippsland Highlands. Jenkin (1962) has recognized the following units within the Sunkland:

(a) *Koo-wee-rup Plain*

A flat-lying area which is virtually a coastal plain covered by a veneer of Quaternary fluviatile and aeolian deposits. The limits of the plain are defined by the traces of the Clyde Monocline, Heath Hill Fault, the subsurface Lang Lang Fault, and the north shore of Westernport Bay.

(b) *Lang Lang Lowlands*

This unit consists of a group of tilted blocks between the southeast corner of the Koo-wee-rup plain and the Heath Hill Fault. It includes slightly undulating country, part of which now lies beneath the waters of the Bay.

(c) *Central Ridge*

This constitutes the higher land on Phillip and French Islands, composed of Mesozoic sedimentary rocks and early Tertiary volcanics. Its margins are controlled by faults such as the Tankerton, Wellington, Corinella and Brella Faults.

(d) *French Island Lowlands*

An area northwest of the Tankerton Fault covered by aeolian deposits with swamps and lakes in the low-lying interdune and sand sheet areas.

(e) *The Bass Plain*

This area comprises the flat alluvial plain of the Bass River which is incised along the down thrown side of the Bass Fault. The unit also includes the flat country of the Bass River delta and appears

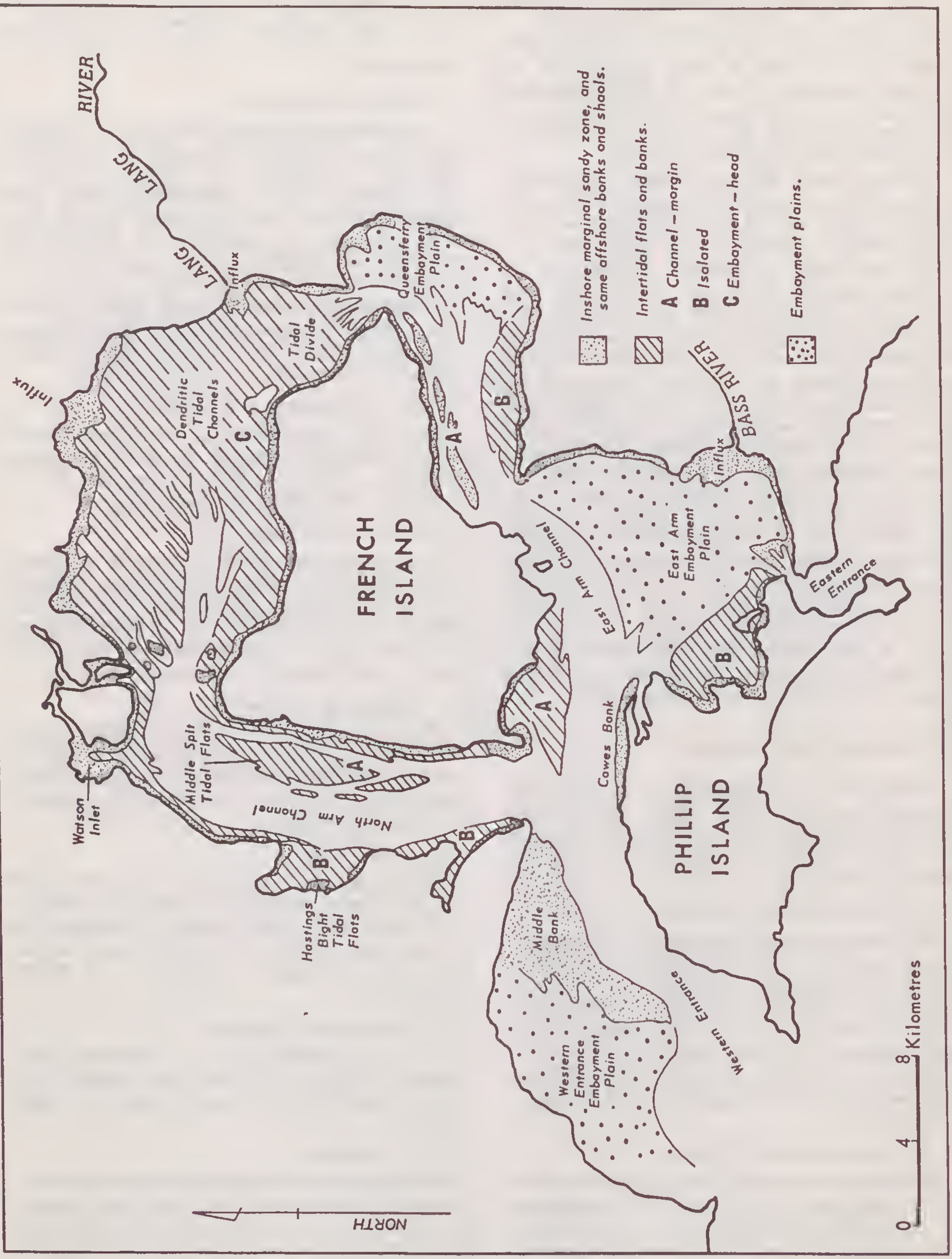

FIG. 2—Morphological systems of Westernport Bay.

to pass offshore into the East Arm Embayment Plain.

(f) *Westernport Bay*

Jenkin (1962) has described the drainage of the area surrounding Westernport Bay as essentially a betrunked river system resulting from the last post-glacial rise of sea level. Streams entering the Bay from the Mornington Peninsula and the South Gippsland Highlands are actively eroding, as demonstrated by the development of deltas. The natural drainage system on the Koo-wee-rup plain has been considerably hampered by aeolian deposits, vegetation and perhaps the effects of back tilting or subsidence of fault blocks leading to the development of extensive swamp areas. Thompson (1974) has referred to the artificial construction of drainage channels which effectively drained the area, causing rejuvenation of the main rivers, the Bunyip and the Lang Lang. The Lang Lang River is now actively forming a delta where it enters Westernport Bay and similar deposits are forming at the mouths of the Bunyip River and Cardinia Creek.

Marsden and Mallett (1975) have discussed in detail the development of both the marginal and offshore morphology of Westernport Bay and interacting sedimentation characteristics, in which sea-level fluctuations, including a relative fall of 1 to 2 m since the mid-Holocene, have been a notable factor.

The drowned embayment morphology is essentially controlled by distribution and erosion of bedrock rather than by sediment-constructed features, and this has resulted in linear, elongate major channel systems. This highlights the relative lack of land-derived sediment input into the Bay. Tidal processes dominate, but wave-action is important because of the general orientation of the Western Entrance and the major arms of the Bay with respect to the dominant wind directions. The Western Entrance opens towards the southwest through a cliffed coastline to the high wave-energy zone of Bass Strait, and is the major channel. The Eastern Entrance is relatively minor, having been opened only recently, probably at or near the time of high sea level in the Holocene, and since enlarged by scour associated with high tidal velocities. Morphological and sedimentation changes are probably still occurring.

Many morphological units have been recognized by Marsden and Mallett (1975) in Westernport Bay. Each has significantly different characteristics, arising from differences in geological history or in sensitivity to variations in present-day physical and other controlling processes. Varying numbers of individual morphological units sharing common characteristics have been grouped into eight morphological systems outlined below.

However, it must be stressed that, within this generalization, local variations of the processes operating in the Bay result in many variant units, which have been revealed by detailed examination. This lack of uniformity is a dominant characteristic of the morphological units of the Bay. Hence extrapolation of physical and sedimentation data over large distances could be hazardous.

Morphological Systems (Fig. 2)

1. *Beaches and Rock Platforms.* Beaches and other constructional features, and erosional platforms, cliffs, etc. occur discontinuously.

2. *Salt Marsh Zone,* normally lying landward of the mangrove zone and fully inundated only periodically, at high-water spring tides and in storms. Sediments are generally clayey, with some peats which are often impure. The zone is characteristically cut by small meandering tidal creeks.

3. *Mangrove Zone.* This lies just below the high-tide mark, is well defined and extensive, although relatively narrow. Sediments are normally muddy, but stabilized.

4. *Inshore Marginal Sandy Zone.* Generally grass-free, and consists of sand with varying proportions of mud. It forms a very persistent zone around Westernport Bay, lying marginal and offshore from a variety of coastal features, and sloping very gently outwards to grassed tidal flat areas which may be muddy rather than sandy. Characteristically it shows features arising from interaction between onshore-offshore, and longshore movements. There are, however, three significant modifications to this zone, namely:

(a) where longshore movements are dominant, e.g. Cowes Bank,

(b) in inlets which show more uniform, lower-energy movements, e.g. Watsons Inlet,

(c) where land-derived sediment influxes occur, e.g. Bass River delta, and where deltas develop offshore from man-made swamp drains.

5. *Intertidal Flats and Banks* occupy approximately 1/3 of the Bay area and show the greatest variability in aspect, in configuration and in sediment type. They are characteristically grassed, are largely exposed at low tide and usually dissected by channels. Morphologically, three types can be distinguished:

(a) elongate channel-margin flats and banks (bars) with linear channels, e.g. Middle Spit Tidal Flats.

(b) relatively small, isolated flats with dendritic to meandering channels, e.g. Hastings Bight Tidal

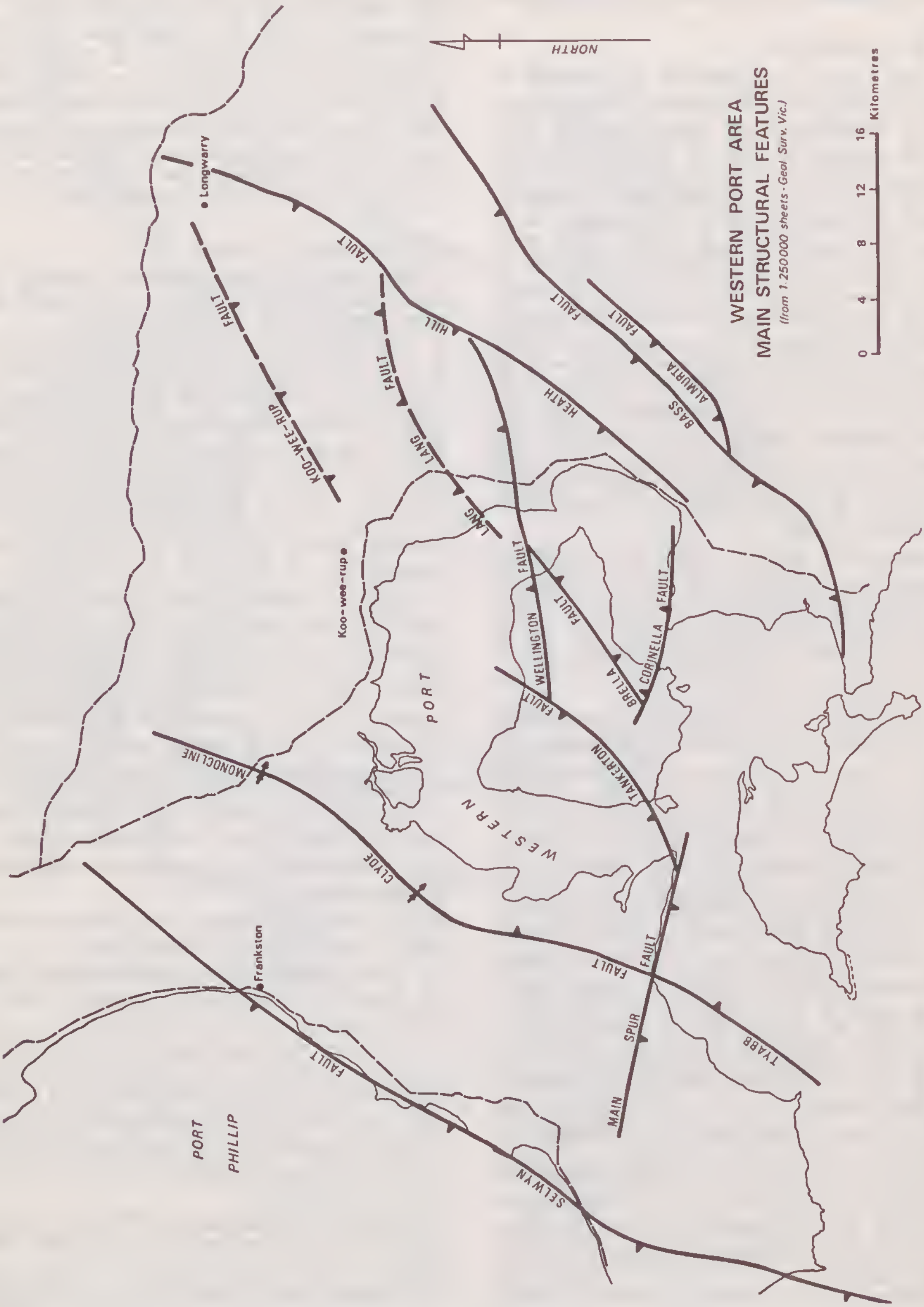

FIG. 3—Main structures of the Westernport area.

Flats, which owe their existence and individual characteristics largely to the pre-existing morphology, and often to their sheltered aspect.

(c) extensive embayment-head flats with dominantly dendritic channel patterns.

Normally the seaward margins of the flats descend steeply, or almost vertically into channels, and in the landward direction shelve to the Inshore Marginal Sandy Zone. Areas of overwash sand accumulation occur on and within the flats, particularly along channel margins.

6. *Offshore Banks and Shoals*. These show grass-free or poorly grassed characteristics similar to the Inshore Marginal Sandy Zone. The offshore banks are, however, mostly subtidal, and consist of mobile sand, characteristically showing large-scale bedforms indicating periods of high-energy transport. Middle Bank is the largest of these.

7. *Embayment Plains* are permanently submerged. They have relatively low but irregular relief, and slope gently to their deepest margin, where they are terminated abruptly by a steep descent into a large tidal channel. The inner margins are variable, commonly being formed by the outer fronts of shallower banks and tidal flats, which may partially enclose the plain. Three Embayment Plain areas have been delineated (Western Entrance, East Arm and Queensferry). The former two owe their morphology in part to an inherited topography, but features of the latter suggest the influence of faulting also.

8. *Tidal Channel Systems*. These comprise (a) the minor dendritic channels and tidal creeks incised into the embayment-head flats flanking either side of the tidal watershed, and into the other smaller tidal flat areas (b) the main trunk systems in the North Arm and East Arm, leading to the dominant Western Entrance, and (c) the more limited channel system of the Eastern Entrance. Flood-dominant and ebb-dominant channels move both water and sediment in complex patterns, forming bars, and also over-wash sands on the margins of tidal flats and banks.

MAIN STRUCTURAL FEATURES (Fig. 3)

The major structural features which led to the formation of the Sunkland are the normal faults along the east and west margins. The Tyabb Fault which extends from near Flinders to northwest of Hastings was described by Keble (1950) as a bedrock strike fault with a vertical displacement of approximately 60 m. He considered that the presence of terraces and hanging valleys along the eastern edge of the Peninsula was evidence of intermittent movement in recent times. However, Jenkin (1962) suggested that these features may be the result of Quaternary sea-level changes. The northeasterly extension of the Tyabb Fault is the Clyde Monocline which eventually loses topographic expression and dies out.

On the eastern side of the Sunkland, the Heath Hill Fault forms a pronounced escarpment trending north northeast until it also dies away to the north. This fault has an estimated displacement of 300 m producing pronounced steep dips in the nearby Tertiary sediments. Further to the east and sub-parallel to the Heath Hill Fault is the Bass Fault with a pronounced escarpment along the eastern side of the Bass River valley. The fault has produced drag effects in the bedding of the Lower Cretaceous sediments. Parallel to the Bass Fault is the Almurta Fault and between them a back-tilted block, infaulting Tertiary sediments and Thorpdale Volcanics.

The Tankerton Fault cuts across the western and northwest part of French Island separating the block of Mesozoic rocks forming the core of the island from downfaulted Tertiary sediments to the northwest. The Wellington Fault crosses the Tankerton Fault with an east-west scarp across the northern part of French Island with downthrow to the north. This fault may extend as far as the Heath Hill Fault to the east. The Corinella Fault is described by Jenkin (1962) and follows the coastline east of Corinella where masses of ferruginous sandstone occur along the shoreline. Jenkin (1962) suggested that the ironstone had formed along the actual fault line, but Thompson (1974) suggests that the ironstone may be a development at the unconformity between the Thorpdale Volcanics and the overlying Baxter Formation gravels.

The Brella Fault has been mapped by Jenkin (1962) along the east side of French Island where it again defines the edge of the Mesozoic rocks, with downfaulted Tertiary Volcanics and sediments to the east. The Lang Lang Fault and the Koo-wee-rup Fault do not have any obvious surface expression, but close drilling into the Tertiary sediments has established the presence of these two structures.

Age of Faulting

Since at least the Jurassic, block faulting in this region has played a major role in the vulcanicity and sedimentary rock deposition. However, the present form of the Sunkland probably owes its origin to late Pliocene to Early Pleistocene movements along the major boundary faults. The escarpments of the Heath Hill Fault and the Bass Fault in particular show many youthful geological features.

DISTRIBUTION OF THE GEOLOGICAL FORMATIONS (Fig. 4; Table 1)

Ordovician

The bedrock ranges in age from Ordovician to Lower Devonian. Ordovician rocks outcrop on the Mornington Peninsula and consist of a sequence of siltstone, cherty mudstone and sandstone ranging from lowermost Lower Ordovician to Upper Ordovician in age. Keble (1950) established mappable zones in these rocks based on the graptolite assemblage. The rocks are folded into a broad anticlinorium and show strongly developed cleavage.

Silurian to Lower Devonian

Sedimentary rocks of this age, including mudstone, siltstone, shale and some sandstone, outcrop along the eastern edge of the Mornington Peninsula. They outcrop in the foothill country along the northern margin of the Sunklands where they are deeply weathered to clay in some parts. The rocks are mainly unfossiliferous, but occasional graptolites give the age. The rocks are folded but do not exhibit the cleavage typical of the Ordovician rocks.

Silurian-Lower Devonian rocks have been penetrated by water bores beneath the Cainozoic formations in the Koo-wee-rup area, Phillip Island and French Island (Jenkin 1962).

Table 1

			Rock Unit
Cainozoic	Quaternary	Holocene Pleistocene	Cranbourne Sand Heath Hill Silt
	Tertiary	Pliocene Miocene Oligocene Eogene Paleocene	Baxter Formation Sherwood Marl Thorpdale Volcanics Childers Formation
Mesozoic	Lower Cretaceous		Strzelecki Group
Palaeozoic	Devonian Silurian Ordovician		Basement (Sandstone, Siltstone, Mudstone, Granite, Granodiorite)

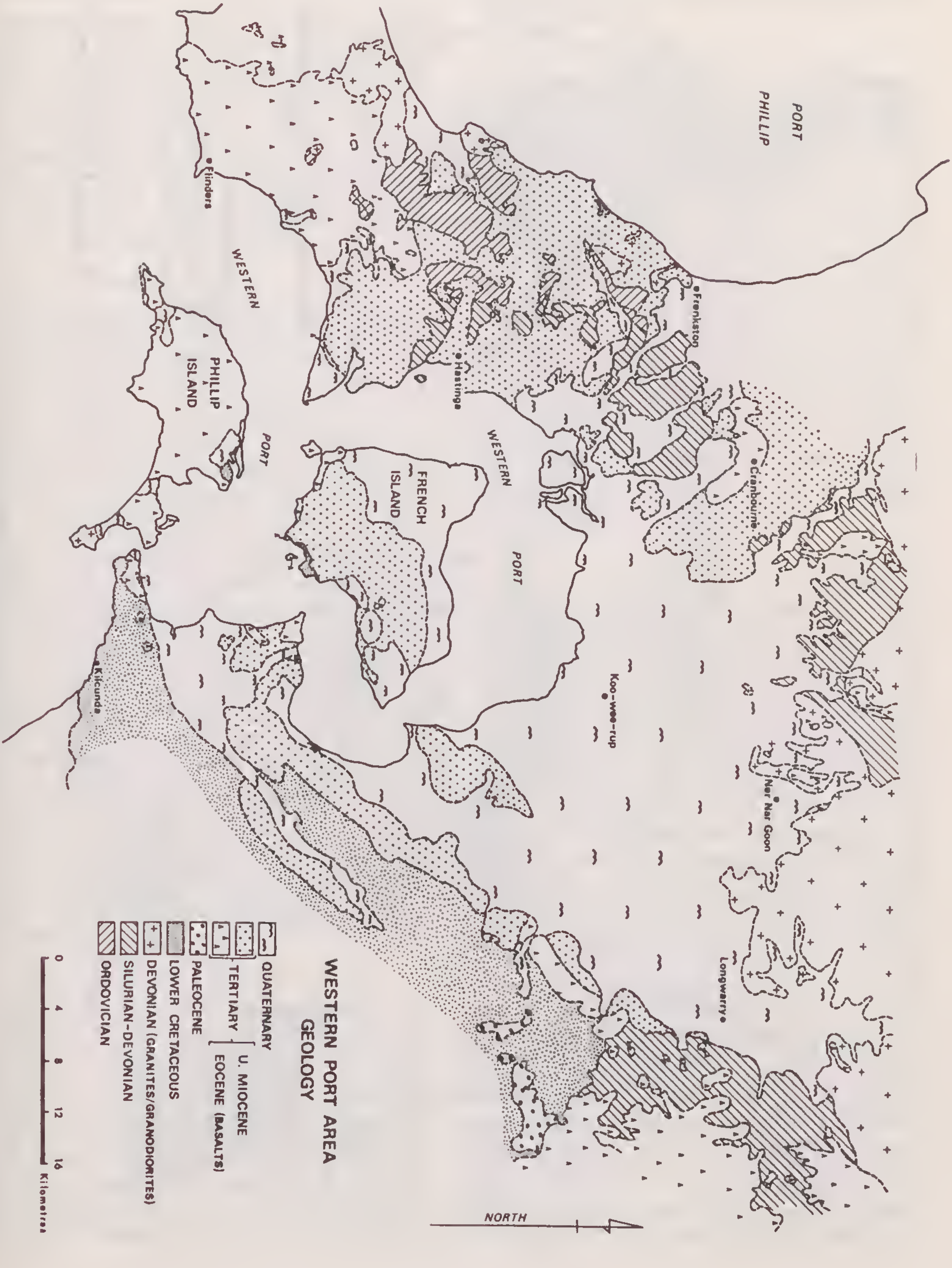

FIG. 4—Westernport area geology.

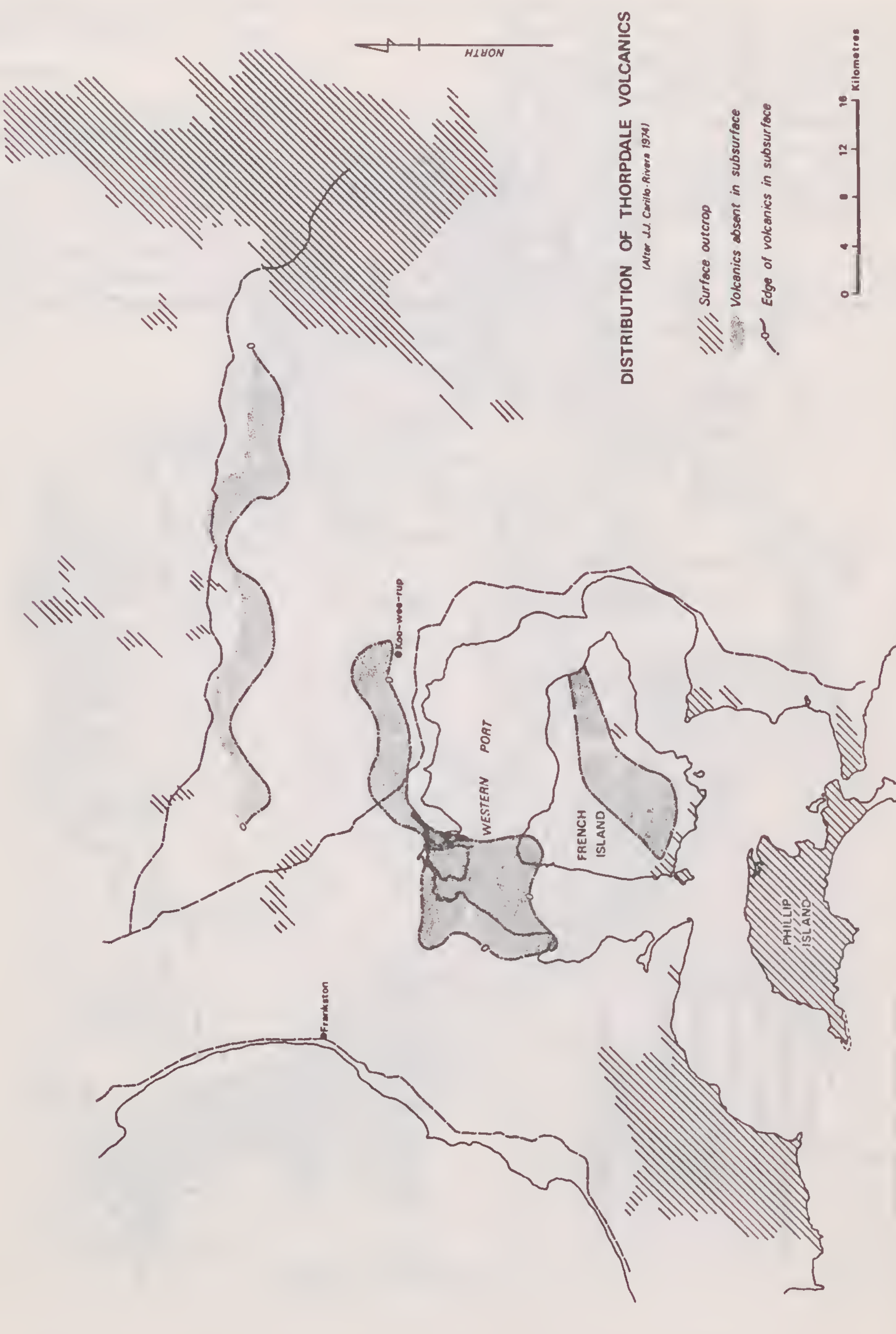

FIG. 5—Distribution of the Thorpdale Volcanics.

Upper Devonian

Granitic masses intrude the bedrock of the Mornington Peninsula as discrete masses on the Arthurs Seat Ridge (Dromana Granite), Mt. Martha, Mt. Eliza and to the north in the foothill country of Packenham and Tynong. Granite also outcrops at Cape Woolamai on the southeast tip of Phillip Island. The granitic masses are typical of the discordant Upper Devonian granite massifs of Central Victoria. In the vicinity of the Westernport area they are deeply weathered, giving rise to coarse clayey sand and sandy clay.

Lower Cretaceous

Sedimentary rocks of this age form the South Gippsland Highlands along the eastern margin of the Sunkland, and outcrops have been recorded on Phillip Island at Rhyll, and along the southern coast of French Island (Jenkin 1962). Non-marine feldspathic sandstone, mudstone, shale and conglomerate were deposited in an east-west rift or trough which formed across the southern part of Victoria after the Triassic. The main trough was divided into two separate basins by the basement high of the present Mornington Peninsula: Otway Basin to the west, the Gippsland Basin to the east. The Lower Cretaceous sediments in the Westernport area are near the western limit of the Gippsland Basin and represent marginal deposits in close proximity to the source areas. As evidence of this Jenkin (1962) cites the presence of conglomerate and grit on French Island and on the San Remo Peninsula. The rocks are rich in fossil plant material including the black coal deposits of the old Wonthaggi-Kilcunda coalfields. The age of the rocks has been determined from fossil spores and macro-plant material (Douglas 1969, 1973).

The strata are generally horizontal or gently dipping with some evidence of minor folding. However, steep dips are found adjacent to normal faults which are widespread throughout the exposures.

Tertiary

The Tertiary and Quaternary successions in the Westernport Sunkland and their relationships are difficult to interpret because of the inevitable rapid facies variations both in space and time. These are to be expected in a marginal-marine to shallow embayment area which has been subjected to persistent tectonic activity. The shortage of adequate palaeontological control, both for age and facies determination, means that hypotheses previously advanced on the basis of lithology and broad distribution will need to be clarified by application of other detailed and rigorous basin analysis techniques.

Paleocene-Eocene

Deposits of river gravel, sand and clay occur in the bottoms of ancient river valleys and extend as remnants on other parts of the South Gippsland Highlands, generally beneath the Early Tertiary basaltic rocks. These sediments rest unconformably on the Lower Cretaceous rocks east of the Sunkland, on Devonian granites to the northwest, and on Silurian-Devonian sedimentary rocks in the centre and east. The formation varies in thickness, reaching a maximum of 83 m near Yallock and thinning out towards the north and northwest. The formation has been equated to the Childers Formation of Gippsland and contains some ligneous beds and thin brown coal seams. These sediments are now completely covered by basaltic rocks and in some cases underlie thickness of basalt up to 310 m. Keble (1950) suggests that a buried pre-Thorpdale Volcanic valley existed west of French Island, but Thompson (1974) reported a pre-basaltic valley to the east of French Island.

Eocene

During the Eocene extensive flows of basalt were extruded over the Westernport Bay area, completely blanketing the existing stream valleys and topography (Fig. 5). These volcanics have been correlated with the Thorpdale Volcanics of South Gippsland (Jenkin 1962). Jenkin suggested that the great thickness of basic lavas and associated pyroclastics was a result of discharge from peripheral eruption centres into a graben structure. Eruption centres have been identified on Phillip Island, at Mt. Ararat and in the Flinders and Cranbourne areas. The lavas are predominantly iddingsite and olivine basalts. Thin deposits of alluvial clay, sand, gravel and ligneous clays are interbedded with lavas. Occasionally the sediments contain recognizable plant remains (Jenkin 1974). With the exception of some areas where they occur as residuals, i.e. at Berwick and Narre Warren, the lavas are deeply weathered, giving rise to the deep red soils of the Red Hill-Balnarring district.

A sparker seismic survey (Gunn 1973) by the Bureau of Mineral Resources, in collaboration with the Victorian Mines Department, confirmed that the seabed between Phillip Island, French Island and the Mornington Peninsula is underlain by the Thorpdale Volcanics with a thin sediment cover. Although drilling by the Ports and Harbors Division of the Victorian Department of Public Works in the main shipping channel showed that the basalt surface falls off southwards

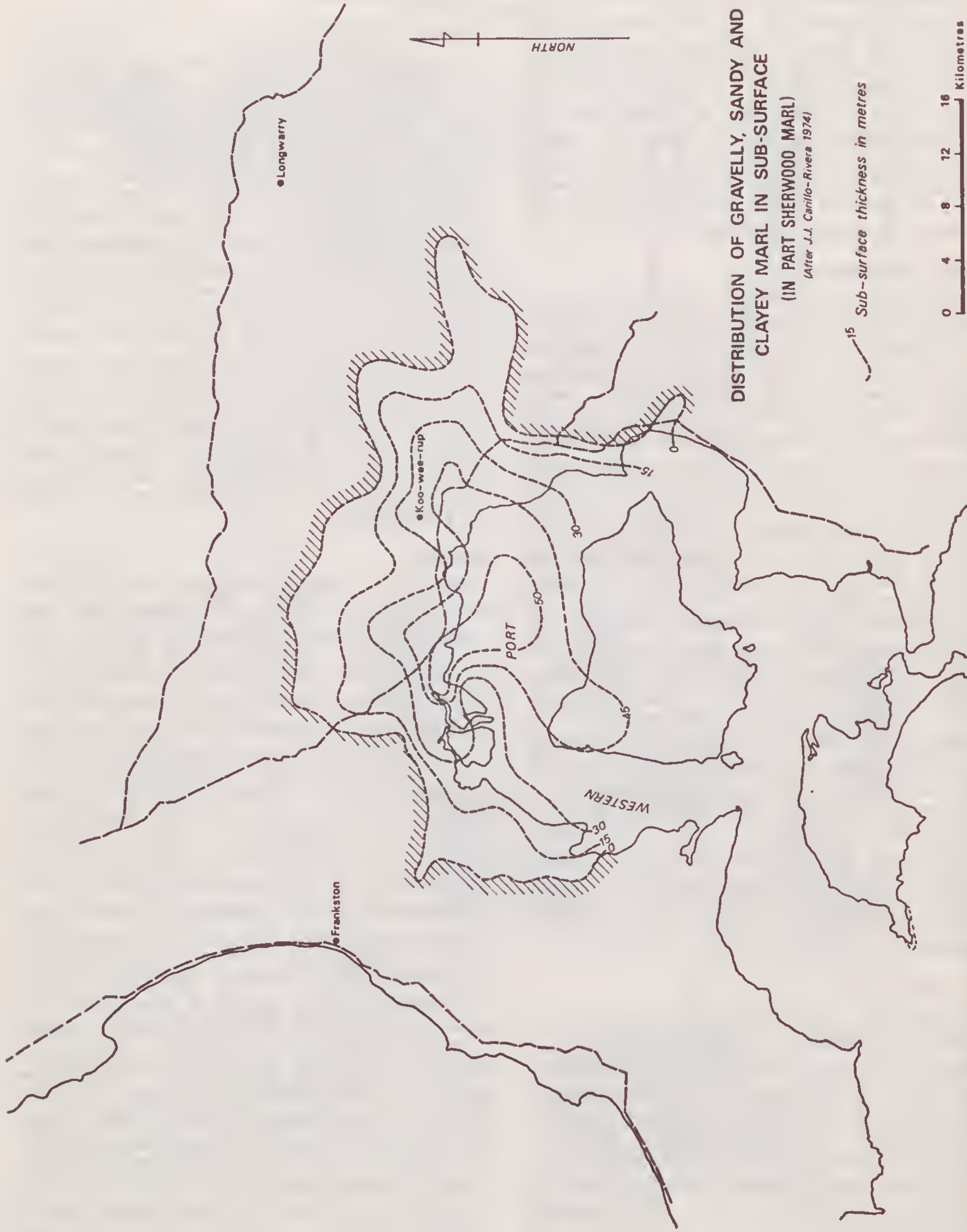

Fig. 6—Distribution of the Sherwood Marl.

from Stony Point, the outcrops of Lower Cretaceous rocks and Thorpdale Volcanics on the south coast of French Island indicate that the post-volcanic cover beneath the main channel is not thick. Off Sandy Point the maximum proved thickness of cover consists of 6 m of Quaternary sediments (Barton 1974).

Miocene

After the widespread basic vulcanicity of the Middle to Late Eocene a comparatively quiescent period of mild erosion followed. This continued into the Early Miocene, when the area began to subside, resulting in a widespread marine transgression and the deposition under shallow conditions of a sequence of sandy marls and limestones (Sherwood Marl). The Sherwood Marl is richly fossiliferous and is regarded as Batesfordian to Balcombian in age (Early to Middle Miocene). The formation underlies most of the southern part of the Koo-wee-rup Plain and extends to the northwest corner of French Island (Fig. 6). It has been intersected by water bores southwest of Lang Lang in the Parish of Corinella, and near Crib Point. It overlies unconformably the Eocene basalts and in some places rests directly on the Palaeozoic basement. During the time of deposition of the Sherwood Marl, surrounding areas such as Mornington Peninsula, the greater part of French Island, Phillip Island and the southeast part of Westernport Bay were land masses. The Flinders limestone recorded by Kitson (1902) may be an equivalent formation.

The maximum development of the Sherwood Marl is between French Island and the mainland. The sparker seismic survey and drilling has indicated a thickness of over 50 m dipping towards the east, upturned by drag in the vicinity of the Wellington Fault. Seismic surveys suggest that the ridge near Sandy Point (on the northeast corner of French Island) is the termination of the Thorpdale Volcanics and the Sherwood Marl.

Present evidence from the channel drilling indicates that the Sherwood Marl pinches out on a basalt palaeo-slope south of Long Island Point and is overlapped to the south by the younger Baxter Formation. The apex of the ridge appears to occur in the vicinity of Stony Point (Barton 1974).

During a mapping programme (1971) by members of the Geology Department, University of Melbourne, a shallow-marine terrigenous facies of Early Miocene age was identified at two localities near Bass. This indicates the possible limit of the basin towards the southeast of the Sunkland (Tickell 1971). Gravelly, coarse sands to clayey sands, all heavily ferruginized, lie immediately on Older Volcanics, and contain a poorly preserved fauna of gastropods, bivalves, bryozoans, and an occasional solitary coral, for which an Early to Middle Miocene age has been determined on the basis of the following identifications (T. A. Darragh, pers. comm.): *Cerithium flemingtonense, Turbo c.f. hamiltonensis, Turritella c.f. murrayana, Haliotis sp., Conus, Eotrigonia, Notocorbula, Chione c.f. cenozoica* and *Glycimeris.* At the locality on Reef Island, the solitary coral *Placotrochus,* together with other forms, indicates slightly deeper water conditions than prevailed at the second locality 1·5 km to the east, on the mainland. At this locality, rocky bottom dwellers such as bryozoa and the molluscs, *Cerithium, Turbo* and *Haliotis* are prominent. At Reef Island, an associated zone of northeasterly trending minor faults suggests that the line of the Heath Hill Fault continues southwesterly (or swings westerly), and possibly was a factor in delineating the shoreline of the Miocene depositional basin. The existence of a nearshore terrigenous facies in this segment of the basin suggests that contemporaneous non-marine post-volcanic sediments could have been deposited further east.

Upper Miocene

After the deposition of Sherwood Marl, uplift resulted in the regression of the sea, and a widespread sequence of fluviatile sandy clay, gravel and sand was deposited over areas of the Mornington Peninsula and the Westernport Bay area. This formation overlies the Sherwood Marl and in other localities rests variously on the Thorpdale Volcanics, Mesozoic rocks and Palaeozoic basement. In surface exposure the sediments are highly ferruginous, oxidized to reddish brown to yellow, and leached. It is only in subsurface that samples of the typical lithologies can be obtained. These consist of fresh fine to coarse grained clayey sand with minor clay lenses and some ligneous matter. The formation has been equated with the Baxter Sandstone which was described by Keble (1950) as ferruginized sandy deposits outcropping on the Mornington Peninsula in a road cutting near Baxter.

Thompson (1974) designated this the Baxter Formation, and reported that sediments tended to become coarser east and northeast of the Westernport Sunkland. He suggested that the Devonian granitic rocks outcropping to the north of the Sunkland were the source of the coarser sands. From the detailed drilling carried out in the Koo-wee-rup plain and around the margins of the Bay by the Victorian Mines Department it would appear that the Baxter Formation has been deposited in an old drainage system. There appear

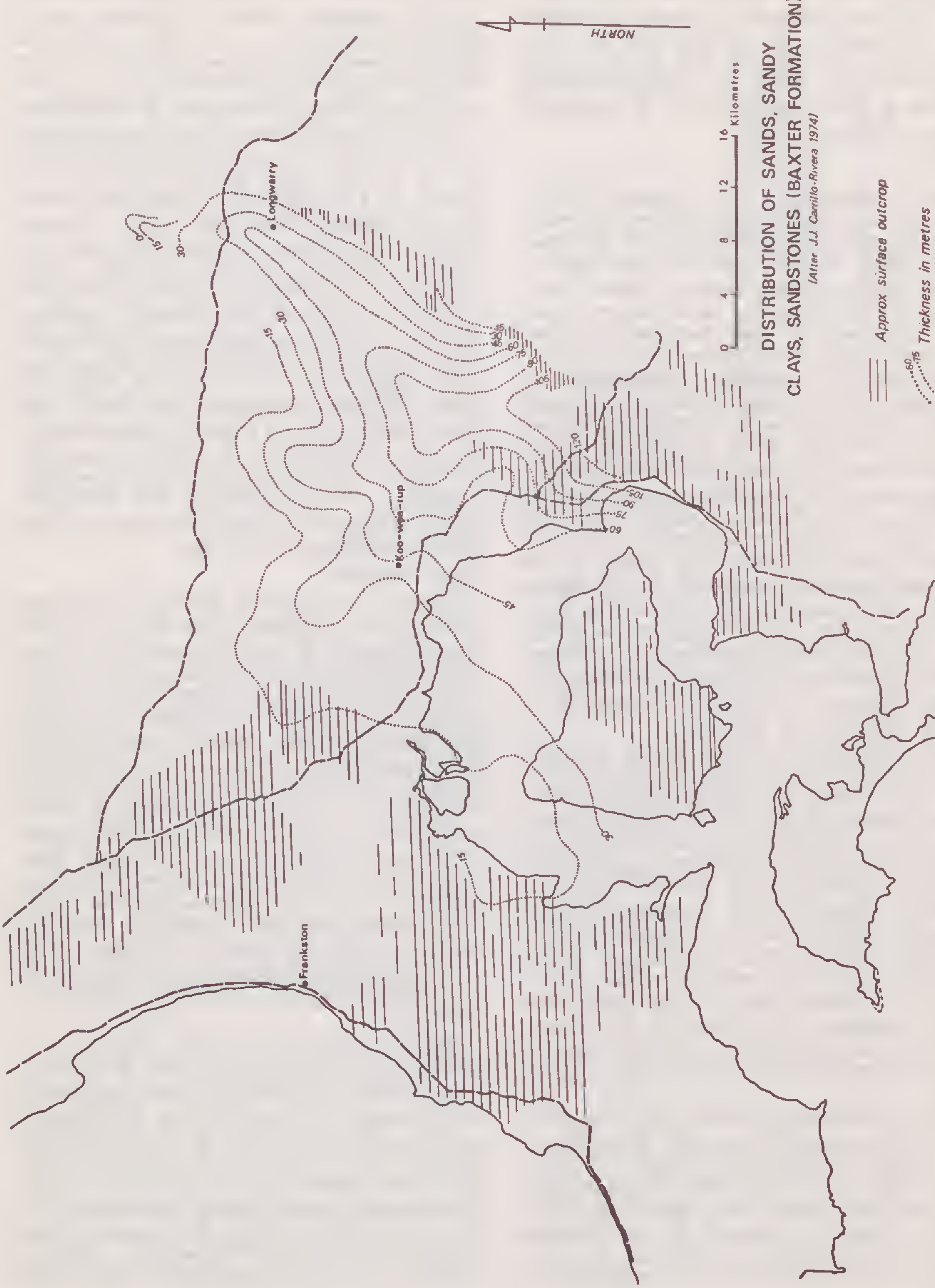

FIG. 7—Distribution of the Baxter Formation.

to be four main broad channels; one along the trend of the present Bunyip River, then swinging southwest towards Koo-wee-rup East; another north-south channel west of Cora-Lynn; a third bearing southwesterly towards Koo-wee-rup and a fourth running northwest beneath Lang Lang. The subsurface distribution of the Formation is shown in Fig. 7. It reaches a maximum thickness beneath Yannathan (146 m) and thins towards margins of the Sunkland.

Detailed mapping along the scarps of the Heath Hill, Bass and Almurta Faults, and in adjacent areas, by the Melbourne University Geology Department (Power 1971, Tickell 1971) has clarified some aspects of the Tertiary stratigraphy for the southern region of the Westernport Sunkland. It has shown that:

(a) In outcrop, Tertiary gravels, etc. consistently overlie the Older Volcanics and are not pre-basaltic as indicated by Jenkin (1962).

(b) Post-basaltic non-marine Tertiary sediments are generally to be equated with the Baxter Formation, although part of the sequence may be equivalent to the terrigenous near-shore Early Miocene facies near Bass (see above).

(c) Areas mapped previously as Grantville Gravels (Jenkin 1962) are occupied partly by fine-grained sediments of Quaternary alluvial fans of limited extent, but mainly by Baxter Formation gravel, sand, etc.

These results are generally consistent with the interpretations of Thompson (1974) for the Heath Hill Block and the more northern part of the Sunkland, and are elaborated below.

(i) Outcropping Tertiary gravels consistently overlie the Older Volcanics, although occasionally the volcanics have been totally denuded, leaving the gravels resting on the Lower Cretaceous. Normally either thin volcanies are present (e.g. less than 10 m west of Almurta), or more often the thickness of volcanics is greater and the base is not seen in outcrop. The normal depositional contact often shows relatively fresh basalt grading into weathered basaltic clay, overlain by gravel dominated by large basaltic clay clasts, followed in turn by gravel with fewer clay clasts. This sequence represents the reworking of the typically deeply-weathered basalt surface material, and prolonged deep weathering prior to the deposition of the gravels may also be indicated by isolated but widely-separated occurrences of limonitic pisolitic soils on the basalt.

The re-interpretation by Thompson (1974) of gravels at Heath Hill as post-basaltic was confirmed and extended to outcrops along the Almurta Fault, southeast of Kernot, where a number of normal gradational contacts are found. The basalt therefore cannot be intrusive or faulted against the gravels (Figs. 8, 9).

Recent investigations have shown that similar deposits resting on basalts are also present beneath the seabed in channel areas north of Phillip Island (Barton 1974).

(ii) The widespread post-basaltic non-marine Tertiary sequence in the southeastern part of the Sunkland has not been differentiated except in the Kernot area. In general it consists of similar lithologies to the Baxter Formation: predominantly clayey sands (with gravels), but with minor, although widespread gravels similar to Unit 1, at Kernot (below).

No assessment can yet be made of the important question of which areas landward of the Early Miocene near-shore facies near Bass were exposed, and therefore subject to deep weathering. Contemporaneous deposition of a terrestrial facies may also have occurred, in which case some of the lower part of the sequence in the Kernot area may be Early Miocene in age, or even older. A brief review of the characteristics of the Kernot sequence is therefore given below.

Four units, totalling 70 m (maximum) thickness, have been differentiated, the oldest of which has a lithology recognizable in places throughout the Bass River area, resting on weathered and eroded basalt. Viewed broadly the lithologies found in Units 3 and 4 at Kernot are similar to those of the widespread and large areas shown as undifferentiated Tertiary sediments.

Unit 1 (oldest): Gravels, ironstained, uncemented, composed largely of granule-size, angular granitic quartz, together with abundant clay clasts up to 10 cm in diameter, often showing relict volcanic textures. Sands occur locally, and occasional relatively pure clays are thought to be reworked weathered basalt.

The evidence of lithologies, bedding sequences and thicknesses (often greater than 1 m) common large-scale and small-scale ripple cross-lamination, and cut-and-fill structures, all indicate relatively widespread, high-energy river floodplain deposition, principally from braided streams such as might be developed on a coastal plain.

Unit 2: Lignites and carbonaecous sands (Stirling 1893; Mines Department Bores 56, 57), with a maximum thickness of 10·5 m. Outcropping lignite also occurs on the Bass River near Glen Forbes. Lower-energy conditions (at least locally) such as coastal plain swamps must have prevailed.

Unit 3: Clayey sands and sandy clays, ironstained with small amounts of gravel, up to 25 m thick. These are only occasionally current-bedded, probably representing a return to fluviatile deposition under lower-energy conditions than Unit 1.

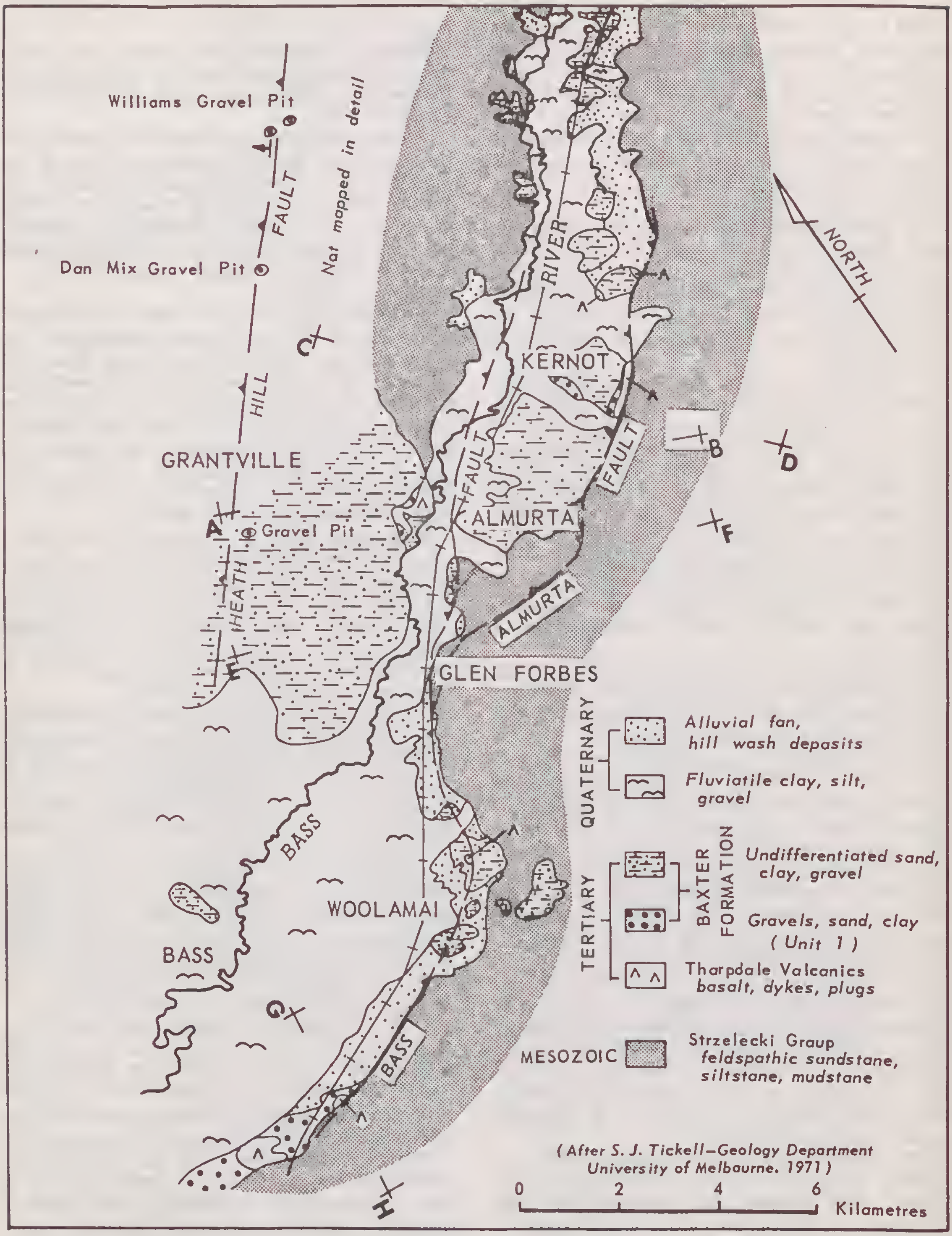

FIG. 8—Geology of the Bass River Valley.

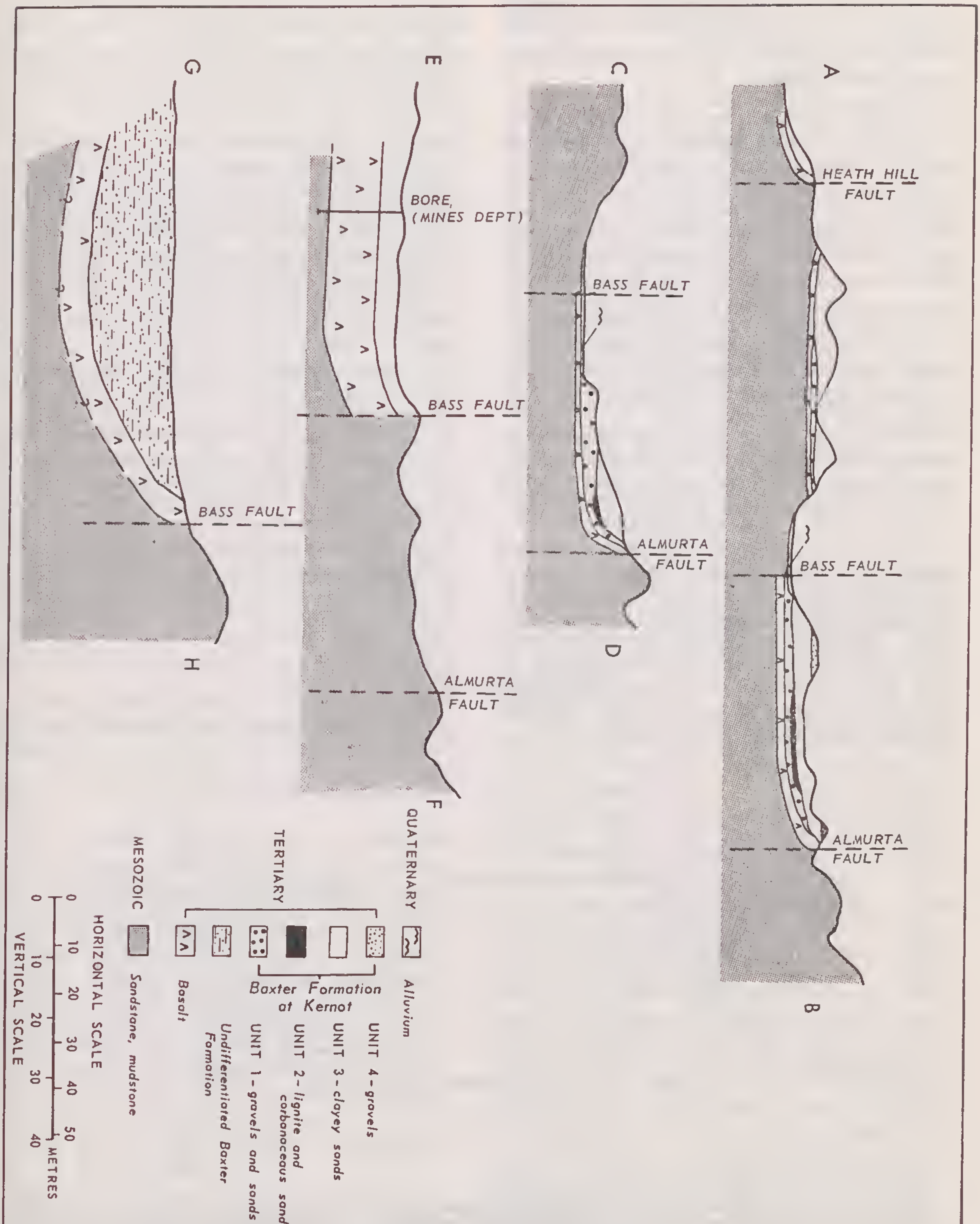

Fig. 9—Geological sections across the Bass River Valley (after Tickell 1971). Refer to Fig. 8.

UNIT 4: (youngest): Gravels, with notably fewer clay clasts, and less ironstained than Unit I, with a maximum thickness of 15 m. Granitic and reef quartz, and chert clasts occur, often relatively well-rounded.

(iii) It has proved impossible to map the Grantville Gravels as a formation, both in the area of the Heath Hill Block and along the Bass and Almurta Faults. Areas previously mapped as Grantville Gravels proved to be (Fig. 8), either:
(a) Quaternary alluvial fan and hill-wash deposits of limited extent, of fine-grained sediments essentially without gravel, derived almost entirely by denudation of Lower Cretaceous litho-feldspathic sandstones and mudstones of the upthrown blocks. The deposits consist of fine sands, silts and silty clays, and form small, relatively thin fans and sheets, sometimes coalescing to form aprons, some interfingering with flood-plain deposits of the Bass River and its tributaries.
(b) Tertiary gravel and clayey sand belonging to the Baxter Formation. Extensive outcrop continuations of these occur away from the fault lines, as a result of rapid decrease in angles of dip, from steep or vertical, to near-horizontal.

The interpretation of the Grantville Gravels as alluvial fan deposits accumulated along scarps of Early Quaternary, possibly partly Late Tertiary age (Jenkin 1962) is contradicted by their widespread distribution and structural relations, their occurrence preserved on the upthrown side of fault blocks, and their sedimentation characteristics, which are similar to fluvial floodplain deposits (e.g. braided stream gravels).

The Melbourne University Geology Department mapping supports the re-interpretation of the Grantville Gravels by Thompson (1974) which was based on Victorian Mines Department drilling at Grantville itself and further north. Illustrative examples are: (a) The section at Williams Gravel Pit (The Gurdies), previously interpreted as a significant unconformity between horizontal Grantville Gravels (formed on the downthrown side of the scarp of the Heath Hill Fault) and underlying steeply dipping Tertiary gravels (Jenkin 1962). This has been re-interpreted (Fig. 10) on the basis that the horizontally-bedded gravels are simply the repetition of the same lithologies of the steeply-dipping Baxter Formation, the quarry having been placed on the line of the Heath Hill Fault.
(b) Sections through the Kernot area, and the area southwest of Woolamai (Fig. 9), which show typical relationships.
(c) The area east of Woolamai, where sands and clayey sands lying to the east of the Bass Fault have the same lithology as Tertiary sediments on the downthrown side, and probably owe their preservation to faulting. Similar lithologies occur also on the upthrown Heath Hill Block (especially at the southwestern end), and in the upper part of the Kernot sequence. They probably also originally covered significant areas of the upthrown block elsewhere, if only as local thin deposits, but as fluviatile rather than alluvial fan deposits.

The Warneet Beds were proposed by Jenkin (1962) as equivalent to the Grantville Gravels.

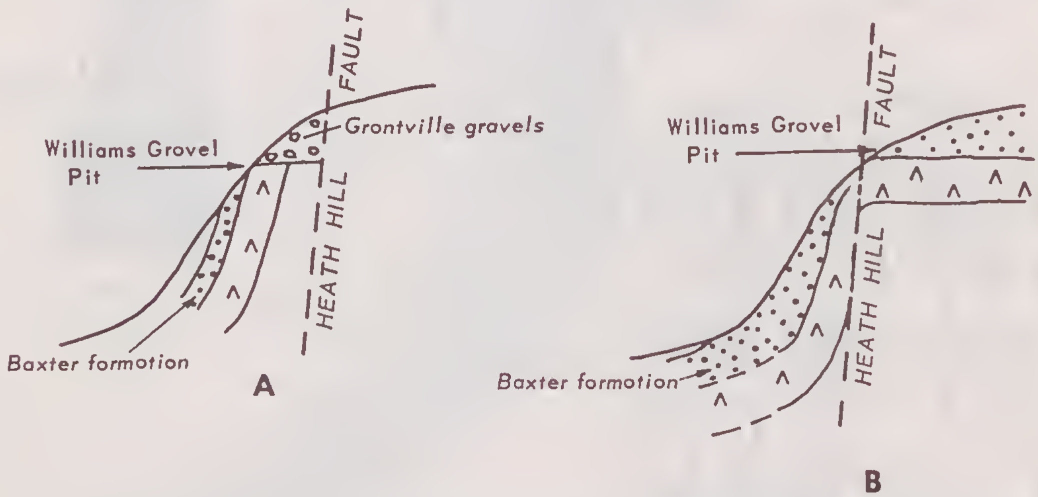

FIG. 10—Diagrammatic interpretations of relationshipsacross the Heath Hill Fault at Williams Gravel Pit: A. Grantville Gravels unconformably overlying BaxterFormation, as described by Jenkin (1962). B. Warping of Baxter Formation (Tickell 1971).

The relationships of small inliers of Warneet Beds, shown outcropping about 2 km north of Warneet (Jenkin 1962), were investigated by Cass (1973) along the State Rivers and Water Supply Commission pipeline trench (Tarago to Westernport).

The excavation passed between these isolated inliers and the main outcrops of Warneet Beds on Cannons Creek. However, the typical Baxter Formation lithologies found elsewhere in the pipeline persisted throughout this section. The Baxter Formation does not outcrop here, however, being covered by a variable, thin veneer (approximately 1 m) of Quaternary swamp clays, peats, etc. and sands. The sands generally occur as sheets, overlying the swamp deposits rather than as Cranbourne Sand inliers, and were probably deposited mainly in broad, shallow drainage zones of the swamp, and by re-distribution following recent sea-level fall. Pedogenetic effects were noted in units of all ages, including these superficial sands. The outcrop area designated as Warneet Beds on the Tooradin-Baxter Road (Jenkin 1962) appears to be of such superficial material.

This indicates that the Warneet Beds at Warneet should probably be regarded as part of the Baxter Formation, which is in agreement with Thompson (1974).

Quaternary

Quaternary deposits cover significant areas of the Westernport Sunkland and most of the Bay floor. The geological controls and processes of the Quaternary are largely operative at the present day, but include interaction between tectonic effects, and patterns of erosion, transport and deposition.

The Quaternary succession and its distribution is not yet known in detail, but a tentative framework for relating onshore and offshore features of the Bay has been presented by Marsden and Mallett (1975), who recognized four main phases of Quaternary history, namely, 1. Faulting, drainage initiation, and erosional downcutting. 2. Extensive fluvial deposition. 3. Erosion (lower sea level), aeolian activity. 4. Holocene marine phase, drowning of the present Bay, with sea level reaching about 1 to 2 m above present level about 5000 to 6000 years B.P. Associated onshore deposition also occurred.

Some of the major Quaternary depositional units are briefly described below.

Pleistocene

Widespread fluvial sedimentation in the earlier part of the Pleistocene resulted in flood plain deposition from the Bass River, now forming a high-level terrace which extends offshore under the East Arm Embayment Plain. The Heath Hill Silt (Thompson 1974) forms an extensive sheet in the northern part of the Sunkland, generally overlying the Baxter Formation. The formation consists of silty clay and silty sand, and contains carbonized wood fragments.

A widespread sheet up to 6 m thick of grey clay and sandy clay occurs northwards from Stony Point: offshore in the North Arm, onshore near Hastings, and extending as far north as Watson's Inlet. Its relationships and age are unknown but the clay may be essentially lacustrine and broadly equivalent to the Heath Hill Silt.

The aeolian Cranbourne Sand (Jenkin 1962) forms siliceous northwesterly trending ridges and sheets in the Cranbourne-Tyabb and Lang Lang-Nyora areas, and also on the northern part of French Island. These presumably formed in the late Pleistocene in a dry period which coincided perhaps with a lower sea level, erosional phase. In parts of the Koo-wee-rup Plain the deposits of the Cranbourne Sand are buried beneath Holocene swamp deposits.

Holocene

A wide variety of Holocene deposits is found in the offshore, littoral and onshore areas and their progressive development to the present-day is significantly controlled by sea-level rise. These are discussed in more detail in Marsden and Mallett (1975).

Drilling near the main shipping channel in the Western Entrance has demonstrated the presence of coarse Quaternary deposits, principally of sandy basalt-pebble and cobble gravel (Barton 1974). These are regarded as fluviatile and hence indicate a sea level of at least 20 m below present-day, a level which occurred approximately 10,000-15,000 years B.P. (Gill 1973, and pers. comm.).

The distribution of the sediment types on the present floor of the Bay shows a generally coarse-to-fine inward gradient which is apparently largely a response to landward transport and re-distribution of sediment. Sand-rich sediments, with quartzose and biogenic carbonate in varying proportions, dominate the channels, but the channel floors also include local muddy sediments, biogenically-bound areas and areas of outcropping older units. The inner, shallower areas of the Bay become muddier, but important interruptions to this trend are seen in the Inshore Marginal Study Zone and elsewhere. An example is the significant development of sand in the Post Office Tidal Flats, north of French Island, attributed to re-working of relic sediment.

Onshore depositional units of Holocene age include beach, lagoon, fluviatile and extensive swamp deposits, the latter particularly seen as sandy clay, peaty clay and peat in the Koo-wee-rup plain area and adjacent valleys.

CHANNEL SUBSTRATE GEOTECHNOLOGY

The floor of the North Arm and western approach channel is largely underlain by Quaternary sediments. In the channel from Stony Point northwards, the bulk of the succession is made up of low-plasticity sandy clays with subordinate medium sands. Farther south, near Sandy Point, sands increase in relative thickness to approximately equal proportions.

The character of the Quaternary sediments in the deeper parts of the outer channel is still not known, but drilling of the channel sea mounds shows that thin, sandy, coarse gravel and uniform (well sorted) sand predominate (Barton 1974).

Clays are of illitic to kaolinitic types with sample unconfined compressive strengths generally less than 0·3 megapascals and a correspondingly low vane shear resistance (standard in-situ vane strength commonly less than 0·01 megapascals). The range of clay consistencies for 257 clay samples is shown in Fig. 11. On shore supra-

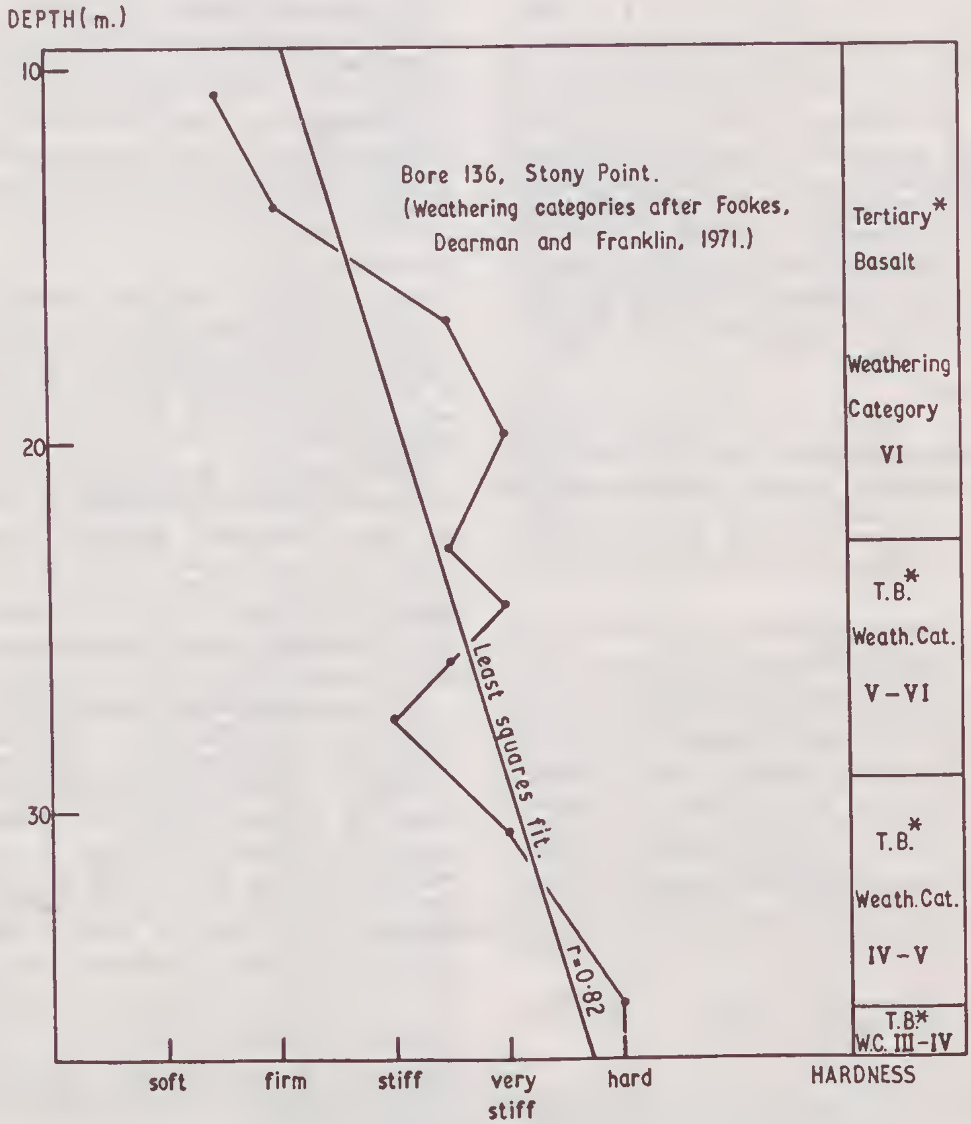

Fig. 11—Range of clay consistencies from channel substrate samples.

phreatic-level clays, as indicated by the State Electricity Commission investigations, possess a considerably higher in-situ strength (Learmonth & Garrett 1966).

The few analyses of the sub-bottom Quaternary sands which have been sized as part of the Victorian Department of Public Works sea-bed investigation show extreme variability between fine and coarse mean size, and from well to poorly sorted, with either a positive or negative skew to the particle-size distribution. Specimen sites extend along the length of the channel and results indicate a possible trend of negative skewness toward the open sea. Three standard penetrometer tests, in the inner harbour areas, gave values indicative of a medium to very dense in-situ state (Barton 1974).

The engineering character of the Quaternary gravel beds in the outer channel areas is still not well known since the materials are difficult to drill, sample and test. The sandy matrix is generally not well cemented but the numerous hard pebbles and cobbles of relatively fresh volcanic rock would tend to hamper dredging operations.

The fluviatile Baxter Formation changes laterally from predominant low-plasticity clays in the area north of Long Island Point, through predominant silts to medium and coarse sands in the vicinity of Stony Point. Iron cementation and a basal ligneous zone are characteristic. Clays are generally soft to firm while sands exhibit medium to high in-situ densities. Four of the coarse sand samples from Stony Point have been analysed to reveal a moderate sorting index with a positively skewed size distribution.

The underlying Sherwood Marl also displays a general lateral southward coarsening from sandy calcareous clay and calcareous silt and fine sand.

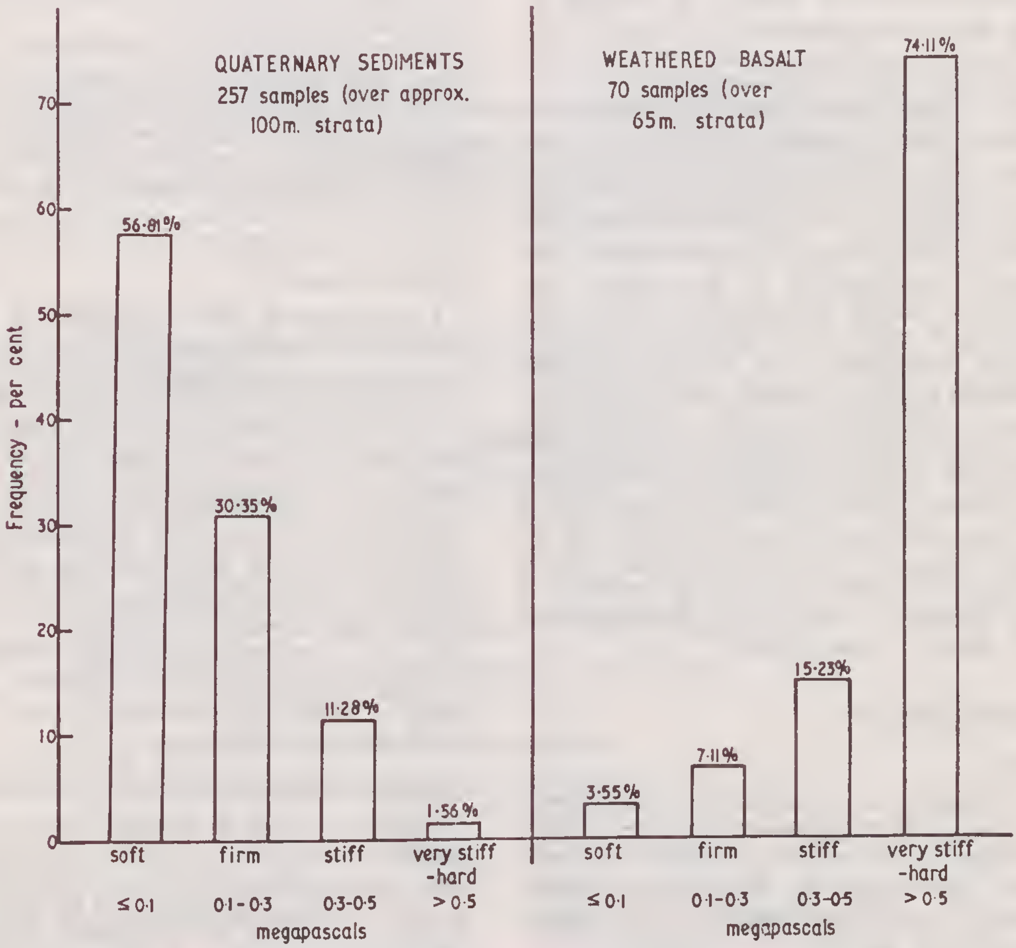

FIG. 12—Correlation of hardness (Field Penetrometer Tests) in residual clays with depth and weathering category.

The stratigraphic terminology is a slight misnomer as the calcareous content is usually too low for strict acceptance of the term marl. The presence of thin, hard, cemented, impure limestone bands, at irregular horizons within the Marl make detailed geotechnical interpretation difficult. In the uncemented zones the matrix is typically a soft, shelly, calcareous clay or silt. It is particularly relevant to note that any contamination of the Sherwood Marl by extraneous solutions could ultimately affect water quality in the Koo-wee-rup aquifer system.

Tertiary volcanic rocks, of which basalt forms the largest proportion, are commonly present near the base of the Tertiary sequence. Variations in degree of weathering are of critical importance to the strength of the basaltic rocks. In the outer channel mounds, relatively fresh hard basalt with overlying Tertiary pebble and cobble gravel occurs at shallow depths. In other areas, a deep weathering profile is preserved. Increase in hardness in residual clay can be correlated (=0·82 and 0·87) with depth and weathering category (Fig. 12). Residual clay contains montmorillonite. Excavation and exposure to air would tend to result in dry cracking and wet expansion, factors which are of considerable engineering significance.

A basal Tertiary clayey conglomerate of variable thickness is known to occur over considerable distances in the northern part of the channel. The engineering characteristics of the material are incompletely known. The matrix is usually uncemented and many of the clasts are of highly weathered sedimentary rock. Lower Cretaceous and Silurian rocks lie beneath the Tertiary and Quaternary sediments. These are generally competent when fresh, and offer engineering usage as a footing for deep-end bearing piles. Over most of the northern areas, where such potential use is more likely, pile depths of over 50 m would be necessary. Since in these areas the upper surface of the 'basement' rocks is frequently weathered, it may be necessary to drive through an incompetent zone to obtain a sound footing.

HYDROGEOLOGY

General

In the Koo-wee-rup and Dalmore areas increasing use was made during the 1960's of high quality groundwater from underlying aquifers. A result was the development of the extensive market-gardening and dairying industries which supply the Melbourne market. In the drought years of 1967–1968 and 1972–1973 these industries placed severe strain on the aquifer system and consequently, after proclamation of the Groundwater Act, 1970, the district was declared a Groundwater Conservation Area, 1971.

Since then the Victorian Mines Department has intensified the hydrogeological study of the area, includiug the intake areas. The objective has been to ascertain whether over-development of the aquifers could result in saline water intrusion, and to provide data to calculate a safe yield from the system.

All the important water-bearing formations in the Westernport area are of Cainozoic age. They are shown in diagrammatic cross-section in Fig. 13. From the hydrogeological point of view the most important geological outcrops which serve as intake areas are:

(1) Rocks of volcanic origin (Thorpdale Volcanics), exposed in the Cranbourne and Drouin West areas.

(2) Sand, gravel and clay, often ferruginized, of the Baxter Formation in the Lang Lang, Drouin West and Cranbourne areas.

The most important privately developed aquifer system taps the Sherwood Marl-Baxter Formation which, compared with the Thorpdale Volcanics, occurs at relatively shallow depths. The Volcanics within the main groundwater basin are not only deep, but also hard, and expensive to drill.

The Aquifer Systems

Childers Formation

This consists of white to grey gravel, at times in a sandy or sandy clay matrix, underlying the eastern side of the Sunkland. It is an important water-bearing unit, but is seldom tapped for private use because of its relatively greater depth. However, it is used as a water source in some areas, e.g. at Lang Lang for the town water supply. Water of this formation has been reported with salinities as low as 390 mg/l TDS and yields obtained are large. The coefficient of transmissivity for the Lang Lang area is of the order of 900 m^2/day. Towards the centre of the groundwater basin the sediments of the formation become finer and poorly sorted resulting in lower yields and the deterioration in water quality (1500 mg/l of TDS).

Thorpdale Volcanics and associated sediments

There is a lack of basaltic rocks in a strip parallel to the present northern coastline of the Bay and extending from the town of Koo-wee-rup to near Warneet. Southwards, as far as the north-western corner of French Island, basalts also appear to be absent. A thickness of more than 100 m of lavas encountered in the Drouin West area gradually decreases towards the north and west. At Flinders a thickness of more than 400 m has been proved, and 300 m on the western tip of Phillip Island.

Hydrologically this formation is of particular importance. The main source of groundwater recharge for the basin is from the outcropping volcanics in the intake area around Drouin. The Thorpdale Volcanics aquifer is occasionally tapped by private bores, e.g. in the vicinity of Cranbourne, where it is found at shallow depth and the basaltic rocks are extensively fractured. Depending on the degree of weathering and intensity of fracturing, the formation has a transmissivity value varying from 12 to 1240 m^2/day. Normally good yields can be obtained, and the water is artesian in the Drouin area, at Lang Lang and on French Island. The water quality does not exceed 1500 mg/l TDS although the iron content is relatively high.

Sherwood Marl

This aquifer is the most intensely developed in the district although the formation is inhomogeneous because of rapid changes in facies. The value of transmissivity ranges from 6 to 810 m^2/day. The water in the Sherwood Marl is generally of high quality but deteriorates rapidly towards the western part of the groundwater basin, where salinities as high as 7500 mg/l TDS have been encountered.

Baxter Formation

Water from this aquifer is used for irrigation and stock supplies and to a certain degree for domestic purposes. The aquifer is confined, and artesian flows have been developed north of the Cranbourne area and towards the south of Lang Lang. The quality of the water is moderately good (1000-2000 mg/l TDS), but normally is has a medium to high iron content.

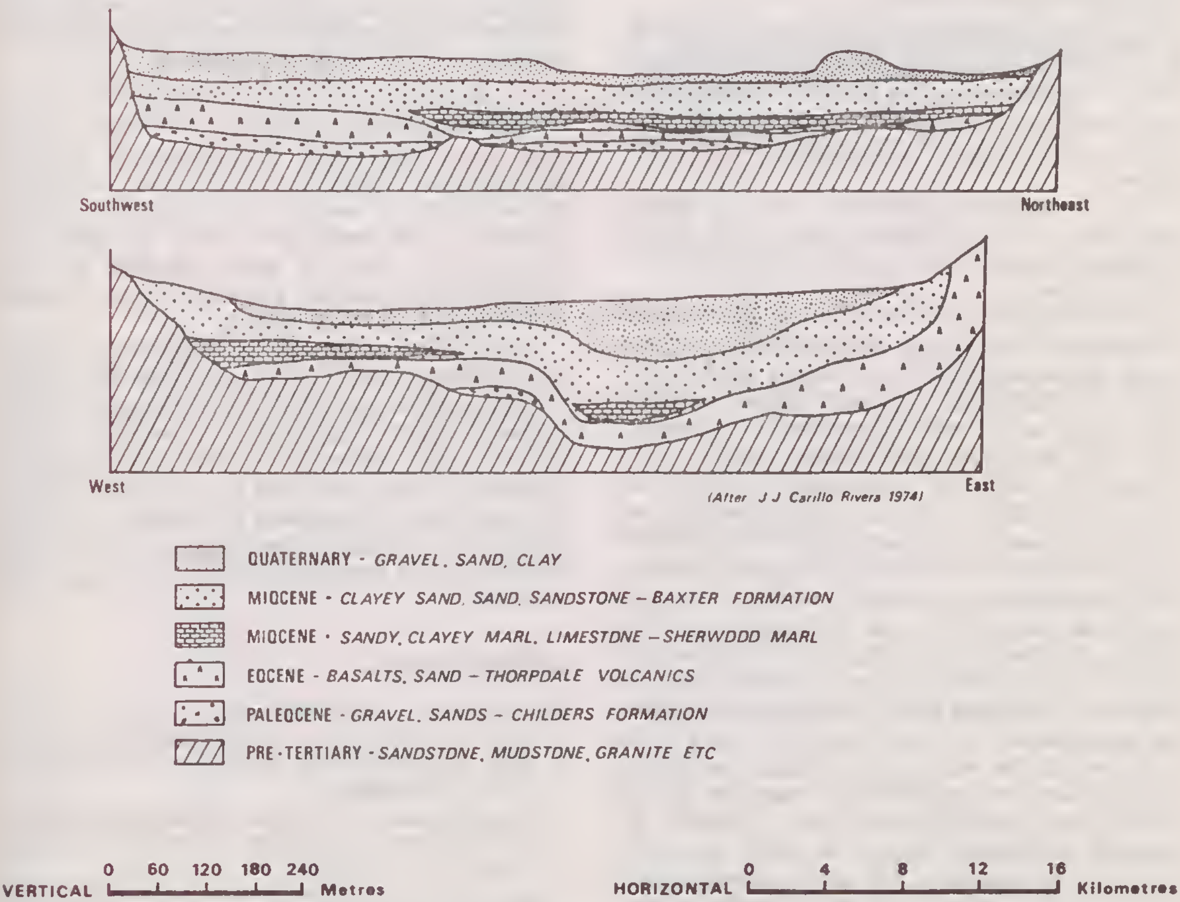

FIG. 13—Diagrammatic cross sections of aquifer systems.

Quaternary deposits

Under this heading are included all formations younger than the Baxter Formation. They include clay, gravel, sand, sandy clay, and silty clay, and may be alluvial, paludal, aeolian or littoral. The most widespread are the alluvial deposits which cover about 72% of the plains area. The swamp deposits are responsible for the peaty clay soils of the Koo-wee-rup and Koo-wee-rup East areas where most of the market-gardening takes place.

The Quaternary deposits thicken rapidly towards the centre of the basin where up to 80 m of sediments have been encountered southwest of Lang Lang. This may suggest a general subsidence in the basin contemporaneous with deposition. Owing to the poor sorting of the sediments, yields of groundwater are normally very small and suitable only for domestic uses. The water quality is quite adequate for this purpose, but the TDS can vary considerably.

Groundwater Problems

When the groundwater resources were originally developed in the Koo-wee-rup area, the water was artesian. The construction of high yielding bores, and increasing numbers of bores over the past decade, has lowered the original potentiometric surface.

At the present time artesian water is encountered only in the Sherwood Marl and Baxter Formation aquifer system in the Cranbourne and Yallock areas.

The estimated extraction rate for 201 licensed groundwater bores used for irrigation purposes in the Koo-wee-rup Dalmore area is of the order of 10 x $10^6 m^3$/year. The total estimated extraction figure would not be reached in a normal 'year', but during drought periods, such as 1967–68 and 1972–73, the total water extracted has exceeded this figure. The amount of groundwater used for domestic and stock supplies is negligible compared with that used for irrigation purposes. The potentiometric surface shows a cone of depression centred on the Dalmore area, into which groundwater is moving from all directions. During the irrigation season a second cone of depression is formed in the Cora-Lynn area inducing groundwater to travel from the Lang Lang area towards the centre of the basin. The overall result affects the groundwater resources in the Cora-Lynne Dalmore areas with a general dewatering, and lateral seepage of saline water into the cone of depression. If saline connate water or sea water is introduced into the aquifer system, then permanent damage will occur.

Although generally from year to year the groundwater levels recover to the equilibrium state of the previous year, the cone of depression in the Dalmore area persists, and thus creates a situation which may induce saline water intrusion. The intrusion may take 20 to 30 years to occur under uncontrolled conditions, but by rigid control of the extraction rates and by artificial recharge the danger can be averted.

Solutions of Overdevelopment Problems

(1) When accurate extraction figures are obtained from the metering being carried out by the State Rivers and Water Supply Commission on irrigation bores, a control programme will be introduced into the Westernport area. This programme will establish pumping limits in time and space for an overall management of the water resources.

(2) The possibility of recharging the systems by injecting treated waste effluent into the aquifers beneath the Tooradin area could be a solution, or the effluent could be used directly for the irrigation of pasture during summer months and thus reduce the amount of water extracted from underground for irrigation purposes.

(3) However, the general solution will not be to reduce pumping throughout the whole of the basin. Pumpage should be encouraged in some areas such as Lang Lang and Yallock, where the groundwater is readily available. The overall problem is not really the amount pumped in a normal year, but the gross pumpage on any particular day, and in a drought year, through the extended pumping season.

In any plans to develop the Westernport region, the important intake areas which feed the aquifer systems must be protected from pollution or any proposal which interferes with natural seepage into the rock systems. The valuable groundwater resources of the area must be carefully managed as long as the area remains an important dairying and market gardening district. Investigation of the possible use of artificial recharge in the area will continue.

REFERENCES

Barton, C. M., 1974. Westernport Sea Bed Investigations: Field Notes and Log Sheets: *Progress Report, CSIRO Division of Applied Geomechanics*, 18 p. (unpublished).

Carillo-Rivera, J. J., 1974. Hydrogeological Maps of Westernport. *Geol. Surv. Rept. 1974/4* Mines Department, Victoria.

Casss, M. R., 1973. The geology of the Tvabb and Koo-wee-rup sections of the Tarago-Westernport Pipeline. Unpub. B.Sc. Hons. Report (part 1), Geology Department, University of Melbourne.

DOUGLAS, J. G., 1969. The Mesozoic Floras of Victoria. Parts 1 and 2. *Geol. Surv. Vict. Memoir* 28. 310 p.

————, 1973. The Mesozoic Floras of Victoria. Part 3. *Geol. Surv. Vict. Memoir* 29. 185 p.

GILL, E. D., 1973. Application of recent hypotheses to changes of sea level in Bass Strait. *Proc. R. Soc. Vict.* 85: 117-124.

GUNN, P. J., 1973. Westernport Sparker Seismic Survey, *Vict. Mines Department Unpublished Report* 1973/85.

HILLS, E. S., 1942. The physiography of the Koo-wee-rup Swamp. *Proc. R. Soc. Vict.* 54: 79-92.

JENKIN, J. J., 1962. The geology and hydrogeology of the Westernport Area. *Dept. of Mines, Victoria, Underground Water Investigation Report*, 5, 81 p.

————, 1974. Geology of the Mornington Peninsula and Westernport. *Geol. Surv. Rept. 1974/3.*

KEBLE, R. A., 1950. The Mornington Peninsula. *Geol. Surv. Vict. Mem.* 17: 84 p.

KITSON, A. E., 1902. Report on the Bryozoan Limestone at Flinders. *Rec. Geol. Surv. Vict.* 1 (1): 49-51.

LEARMONTH, P. & GARRETT, B., 1969. Report on the Engineering Geology of three power station sites in the Tyabb area. *State Electricity Commission of Victoria, Design Division Report.* 5 p. (unpublished).

MARSDEN, M. A. H. & MALLETT, C. W., 1974. Morphology and sediment distribution, Westernport Bay, Victoria, *Report to the Westernport Bay Environment Study, Ministry for Conservation.*

———— & ————, 1975. Quaternary Evolution, Morphology and sediment distribution, Westernport Bay, Victoria. *Proc. R. Soc. Vict.* Vol. 87: 107-137.

MEANS, R. E. & PARKER, J. W., 1964. *Physical properties of Soils*, Merril Books. Inc. Columbia, Ohio, 464 p.

POWER, C. J., 1971. The geology and sedimentology of the Bass River watershed. Unpub. B.Sc. Hons. Report, Geology Department, University of Melbourne.

STIRLING, J., 1893. Topographical and geological survey of Gippsland Carbonaceous area. Quarter Sheets. 67 SW, 34 SW. *Special Report on Victorian Coal Fields No. 2.*

THOMPSON, B. R., 1970. A summary report on the geology of the Westernport Sunkland. *Vict. Mines Department Unpublished Report 1974/69.*

————, 1974. The geology and hydrogeology of Westernport Sunkland and the electric analogue model of the system. *Geol. Surv. Rept.* 1974/1.

TICKELL, S. J., 1971. The geology of the Bass River Area. Unpub. B.Sc. Hons. Report, Geology Department, University of Melbourne